Study of Single Phase Shunt Active Power Filter

A Project Report Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Bachelor of Technology

in

Electrical Engineering

By:

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

PIN-769008, ODISHA

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Under the Supervision of

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To

God and my parents

National Institute Of Technology, Rourkela

Certificate

This is to certify that the thesis entitled **“Study of Single Phase Shunt Active Power Filter”** submitted by **Swayam Saswat** to the National Institute of Technology, Rourkela for the award of degree of **Bachelor of technology** in **Electrical Engineering** is a bona fide record of research carried out by his under my supervision. The content of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Date:

Place:

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Swayam Saswat

ABSTRACT

The use of power electronic devices is increased enormously. And this leads to very low power factor in the power system. Also harmonics are caused by these power electronic devices. Active power filter is a method to reduce harmonics and improve the power factor. This report is intended to provide a method to filter the harmonics and improve the power factor. All goals, design procedures, conclusions are within the report. By this by switching the suitable PWM modulator pulse we can reduce the any no. of harmonics. Mostly 3rd harmonics are present in the power system. Simulation results are also shown which shows that elimination of harmonics can be done with this method.

Hybrid Active Power Filter (HAPF) has been proposed to overcome the disadvantages of APF and HPF. It is a combined system of HPF and APF. Appropriate choice of passive filters and detailed design method for the same is being presented in this thesis, which when combined with APF will eliminate higher order harmonics.

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CHAPTER 1

INTRODUCTION

1.1. Purpose of the project
1.2. Basic theory
1.3. Specifications

1. Introduction

1.1 Purpose of the Project

Harmonics is a great problem in power systems that has become serious recently owing to the wide utilization of force hardware-related supplies. Besides, the information force component of the vast majority of this supplies is poor. Conventionally, a passive power filter and capacitor were used to attenuate the harmonics and improve the input power factor. Static VAR compensators are introduced with many configurations to come out of the situations of power factor correction. But some SVC configurations have very long response time that they are not acceptable for fast fluctuating loads and also lower order harmonics are generated by themselves. Many harmonics-suppression methods based on the technique of power electronics have been developed to solve harmonics problems. One of them is the active power filter.

The problems of power quality is a major in power distribution systems. Due to the development of semiconductor devices, power electronics is revolved a lot and it will go on. The power quality problems are mostly because of the force supplies which are engine drives, electronic balances, variable speed drives (VSD), electronic force supplies and so forth. Non-linear devices creates non-linear loads for which applied voltage is not directly proportional to current. For these loads when voltage is purely sinusoidal still then current is distorted. Non-linear loads are main reasons of harmonic distortion in distribution systems. Through point of common coupling harmonics are injected to power distribution systems. These harmonics causes additional losses, overheating and overloading.

A lot of conventional solutions are improvised to these problems. Simplest conventional solution is passive filtering. But use of inductor and capacitor makes the filter bulky. Also it causes resonance and makes the system more unstable.

The development in the technology of power electronics also spurred active power filter. Basic principle is that using power electronic devices cancel the harmonic currents from nonlinear loads. Before active power filter based on analog circuits. Because of the flexibility and immunity towards the noise signals digital signal processor or microcontroller are used as digital controller. But these methods are not effective for higher order harmonics. This happens because of equipment confinement of examining rate continuously requisition. Also use IGBT switching in APF applications produces noise. To remove noise we need an extra filtering circuit.

Then this hybrid active power filter concepts comes into account. The task of harmonics filtering is done by active and passive filters together. Cancellation of lower order harmonics is done by APF and HPF filters the higher order harmonics. This improves the filtering performance and also cost effective.

1.2 Basic Theory

The control mode of the active power filter can be divided into voltage mode and current mode.

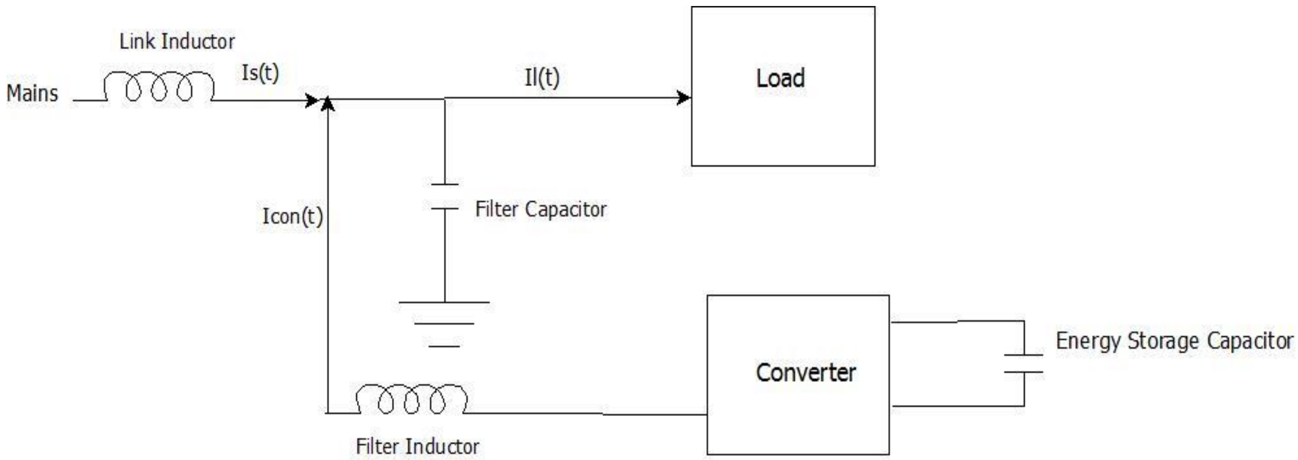

Fig.1 Voltage Control Mode

There is a link inductor used in voltage mode active power filter, which has the disadvantages of slow responses, large volume and higher implementation cost.

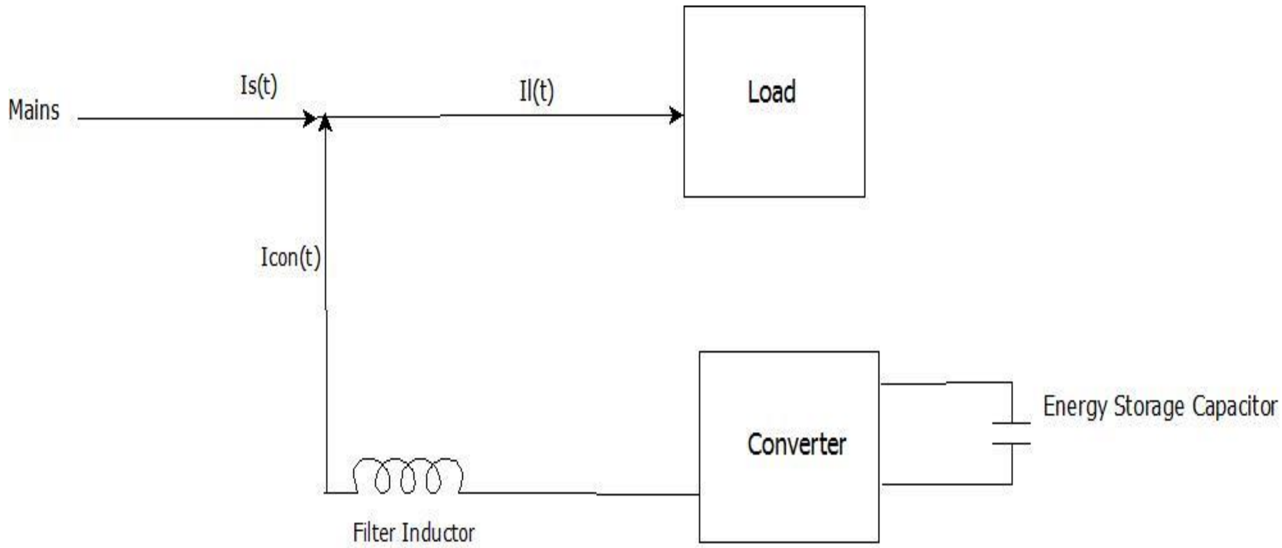

Fig.2 Current Control Mode

The configuration of current mode active power filter is simpler than voltage mode and also its response time is faster. So, it’s widely used. Also, in this the active current wave shaping method used. In this PWM modulator is used to control the reactive power flow through gate driver.

1.3 Specifications

Configuration designers working in today's cutting edge environment need to manage a quickly changing business of electronic items and segments. As new innovation creates, coordinated circuits work speedier and are more diminutive in size. For the control circuit a capacitor, 4 IGBT switches, DC voltmeter, AC ammeter, PI controller, PWM modulator and gate drivers are required. As, per system the specifications are given. For distribution system, capacitor voltage should be maintain at 400V .And range of

Dc voltmeter be 0-400V and that of ac ammeter be 0-100A.

CHAPTER 2

Background and Literature Review

2. Background and Literature Review

2.1 Power quality

Any power problem that results in failure or disoperation of customer equipment manifests itself as an economic burden to the user, or produces negative impacts on the environment. Any power problem that is due to voltage, current or frequency deviation defines power quality. It also results in the failure of customer requirement. Poor power quality can result in lost productivity, lost and corrupt data, damaged equipment and early failure of equipment. There are three key aspects of power quality power factor, harmonics and disturbance. Among these harmonic distortion is the most severe problem. Harmonic distortion is mainly due to the electronic loads (i.e. nonlinear loads). As a result, power conditioning equipments are becoming very essential for the customer utilities. Then many equipments are developed to diminish this problem like tuned passive filters, reactors etc. Active filters or active harmonics conditioners also are used to compensate the harmonic power. For detection and classification of power quality many researches and studies are being conducted. Many methods are being developed like discrete Fourier transform, wavelet transform, data mining etc. Also, active power filter is also a way to improve the power quality. With the help of these disturbance in power quality can be detected and also this problem can be solved.

2.2 Passive Filter

Passive filters are of three types.

- ➔ Single tuned filter
- ➔ Damped filter
- ➔ C-Type high pass filter

In single tuned filter, the quality factor is defined as $Q = X_0/R$.

In damped filter, quality factor is defined as $Q = 1/GX_0$

Where G is the conductance of the resistor in parallel with the inductor.

Quality factor defines the performance of the passive filters.

High pass filters are the second order damped filters. For the harmonics above 25th order, this type of filter is used.

For high pass filter $Q = R/X_0$, where $X_0 = (L/C)^{0.5}$.

If the reactive power supplied by the filter is increased, then filtering performance also improves.

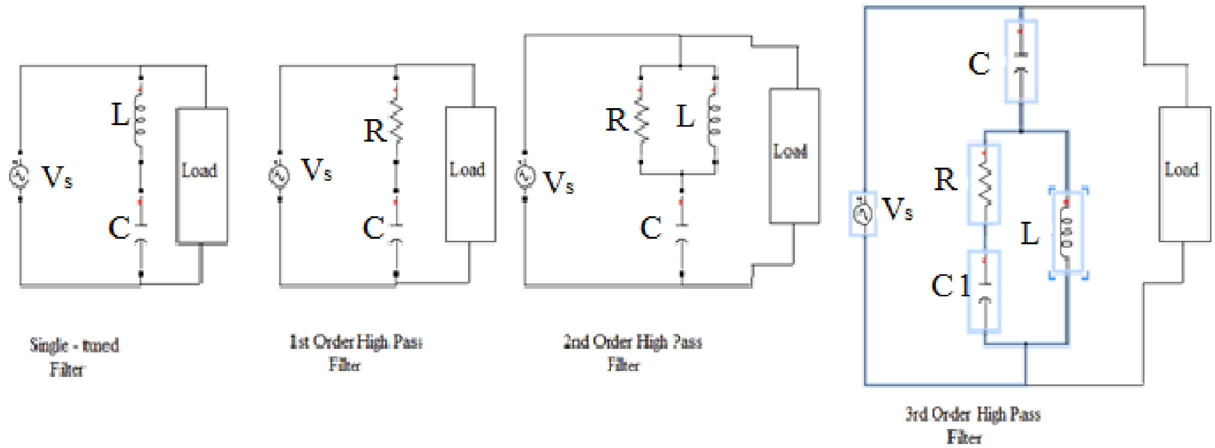

Fig.3 Different Types of Passive Filter

2.3 Active Power Filter

An analog electronic filter is combined with the active components like Opamp, PWM controllers etc. defines the active power filter. A filter is designed which leads to the improvising of the performance, this is included in amplifiers and also this improves the reliability of the filter. Also in these type of filters requirements of inductors reduces due to which it becomes very cheap as compared to other components. Characteristics of the filter remains unaffected because of the amplifier as it prevents the load impedance. There is presence of complex poles and zeroes, even if no bulky inductor is used. With use of variable resistors tuned frequency, quality factor and response can be improvised. Some standard power quality problems can be fixed through these active power filters. Hence, to improvise the power quality depends on which type of active power filter we choose and that depends on the source of problem.

Types of Active power filter

1. Shunt Active Power Filters
2. Series Active Power Filters

2.3.1 Shunt Active Power Filters

The method of removing harmonics in shunt active power filters is by supplying the harmonics current to the load in opposite direction to that of supply from mains. Here, shunt active power filter acts as the current source that supplies the compensating current that the load needs and has a phase shift of 180 deg. Because of which the harmonic currents are cancelled that from the mains supply and from the filter. As per this mains current becomes pure sinusoidal. These filters are considerable to any load that generates the harmonics.

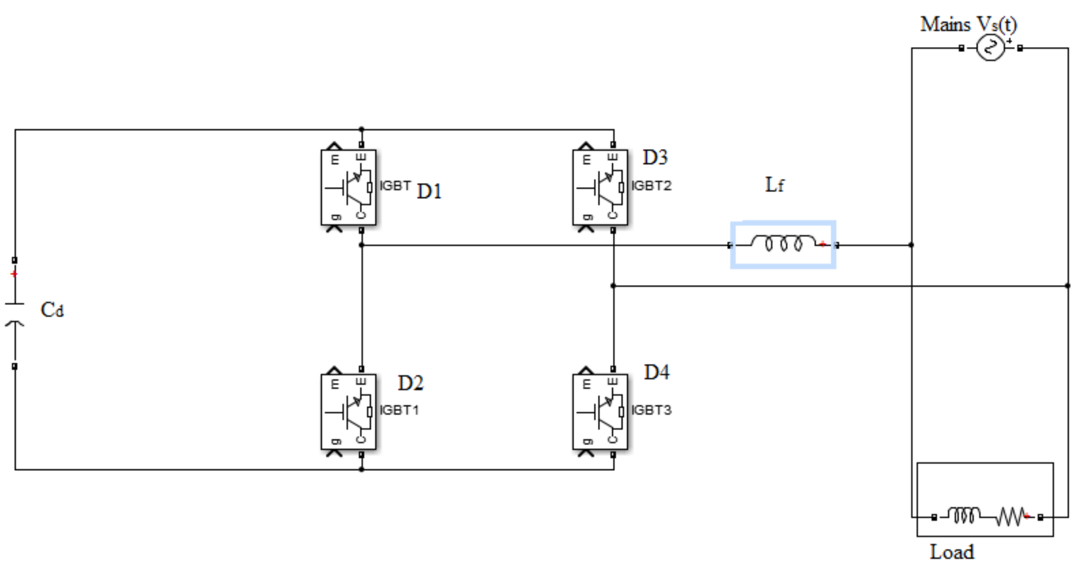

Fig. 4 Shunt APF Circuit Diagram

2.3.2 Series Active Power Filters

At the end of 1980s series active power filters were invented. It basically acts as a voltage source and also it isolates the harmonics from the nonlinear load to the system. When there is poor supply voltage quality it also prevents the equipments from being damaged. Due to this main reason series active power filter is referred. It also prevents the unbalanced voltage system and sags in the voltages. It is also a very good substitute and economical UPS, and also the rating of its components are very low. It in other ways said as the controlled voltage source as it supplies the harmonic voltage components in series with the mains and thus compensates the voltage sags.

CHAPTER 3

METHODOLOGY

3. METHODOLOGY

3.1 Design Procedures

3.1.1 Active power filter Configuration

Fig. 6 shows concept of active power filter. The load may be rectifier or other non-linear load**.**

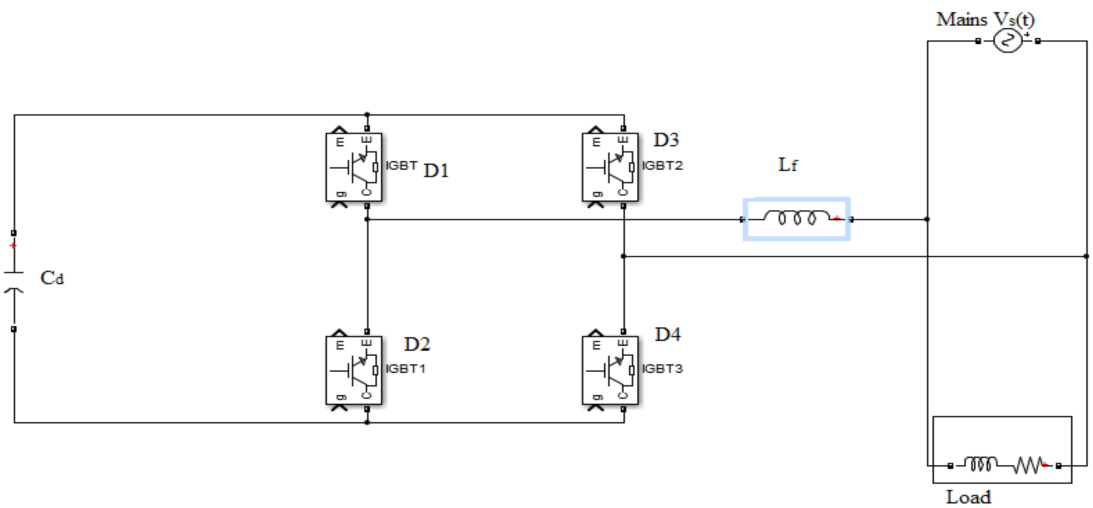

Fig.6 Circuit of Active Power Filter

Assuming the mains voltage is a pure sine-wave, it is represented as

$$V_s(t) = V_p \sin(wt) \qquad \textbf{(3.1)}$$

The nonlinear load current can be represented as

$$I_L(t) = \sum_{n=1}^{\infty} I_n \sin(nwt + \theta_n) \qquad \textbf{(3.2)}$$

Therefore,

$$I_L(t) = I_1 \sin(wt + \theta_1) + \sum_{n=2}^{\infty} I_n \sin(nwt + \theta_n)$$

Assuming a reference sinusoidal signal is represented as

$$I_r = \sin(wt) \qquad \textbf{(3.3)}$$

The amplitude of real part of fundamental load current be,

$$I_x = 1/T(\int I_L(t) I_r(t)\, dt)$$

$$= I_1 \cos\theta_1 \qquad \textbf{(3.4)}$$

Now, $\quad I_{sc}(t) = I_x I_r(t)$

$$= I_1 \cos\theta_1 \sin(wt) \tag{3.5}$$

Hence, calculated compensation current be,

$$I_{cr}(t) = I_L(t) - I_{sc}(t) \tag{3.6}$$

3.1.2 Component Functions

The inductor shown in Fig.6 is used to ensure that the compensation current generated by the convertor is smooth current, an inductor is required to filter out the switching ripple current. For a good dynamic response, the size of this inductor must be as small as possible. If the inductor is too small, it cannot suppress the switching ripple current. It may cause the problem of multi-crossing phenomenon because the change rate of the convertor output current is larger than the slope of the triangle carrier signal. This has the result that the switching frequency is higher than the carrier signal frequency. In addition, the gain of the error amplifier can affect this phenomenon. A PI controller is used to provide approximate amplitude to the mains current. Square wave generator and then sine wave is generated from source for synchronization. Now, the error signal is send to PWM modulator which is required to give the gate pulses for compensation current. To PWM modulator carrier waveform given is triangular wave and through this frequency of gate pulses can be controlled. The load here should be non-linear.

3.2 Component Calculations

In order for the circuit to function properly, the external components need to be calculated carefully. Voltage across the capacitor should be maintained more than 1.41 times of V_{mains} . For the PI controller,

$$K_i = (L + L_0).w_c / (2 * V_{dc}) \tag{3.7}$$

$$K_p = w_c * K_i \tag{3.8}$$

This equations stands for triangular wave of amplitude 1 peak to peak.

Where, $L + L_0$ = Total inductance,

W_c = Triangular wave frequency

V_{dc} = Capacitor voltage

3.3 Simulation Procedure

Figure 7 shows the exact circuit that was used in the Matlab simulation for full wave rectifier.

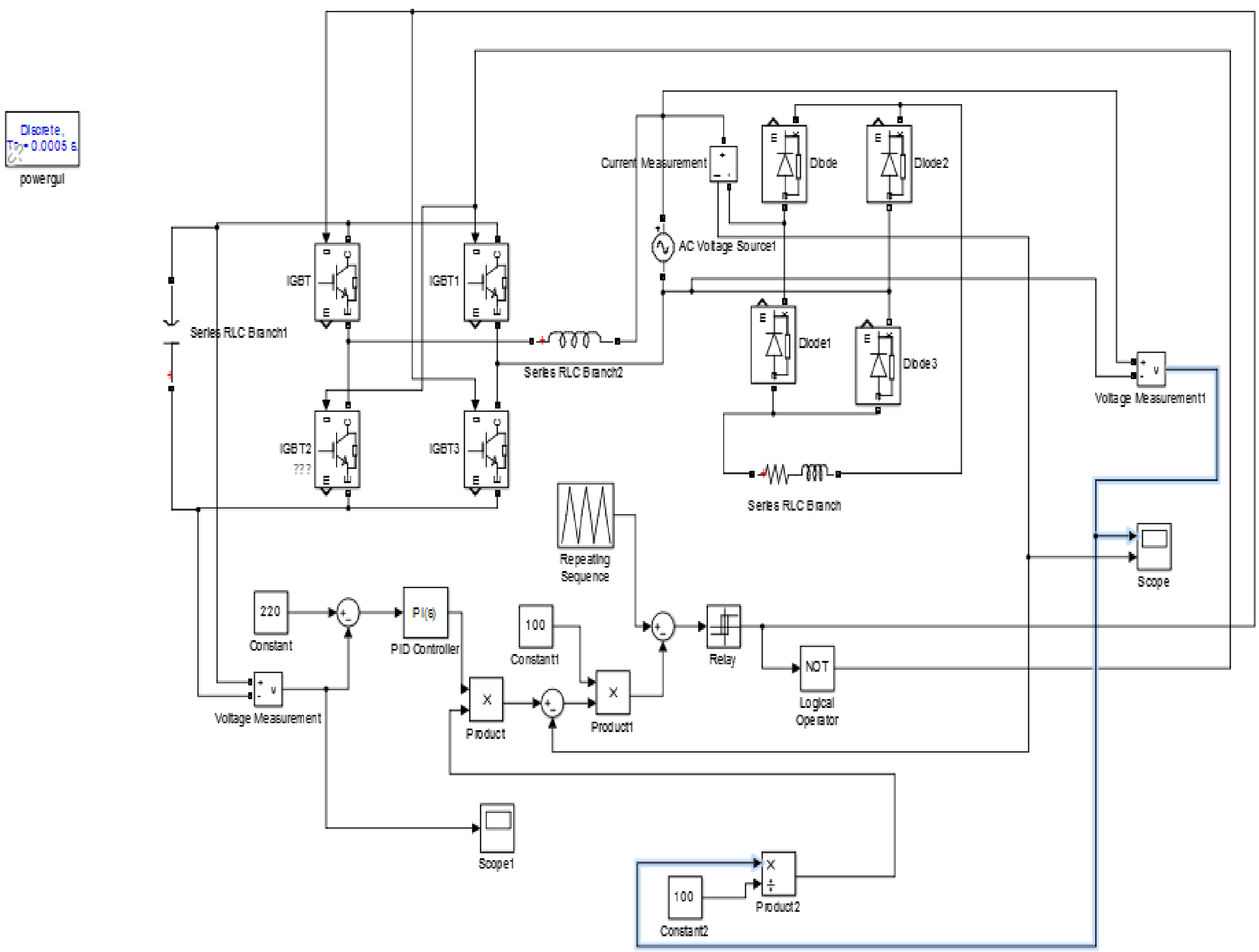

Fig.7 Matlab Simulation for Full Wave Rectifier

Figure 8 shows the exact circuit that was used in the Matlab simulation for half wave rectifier.

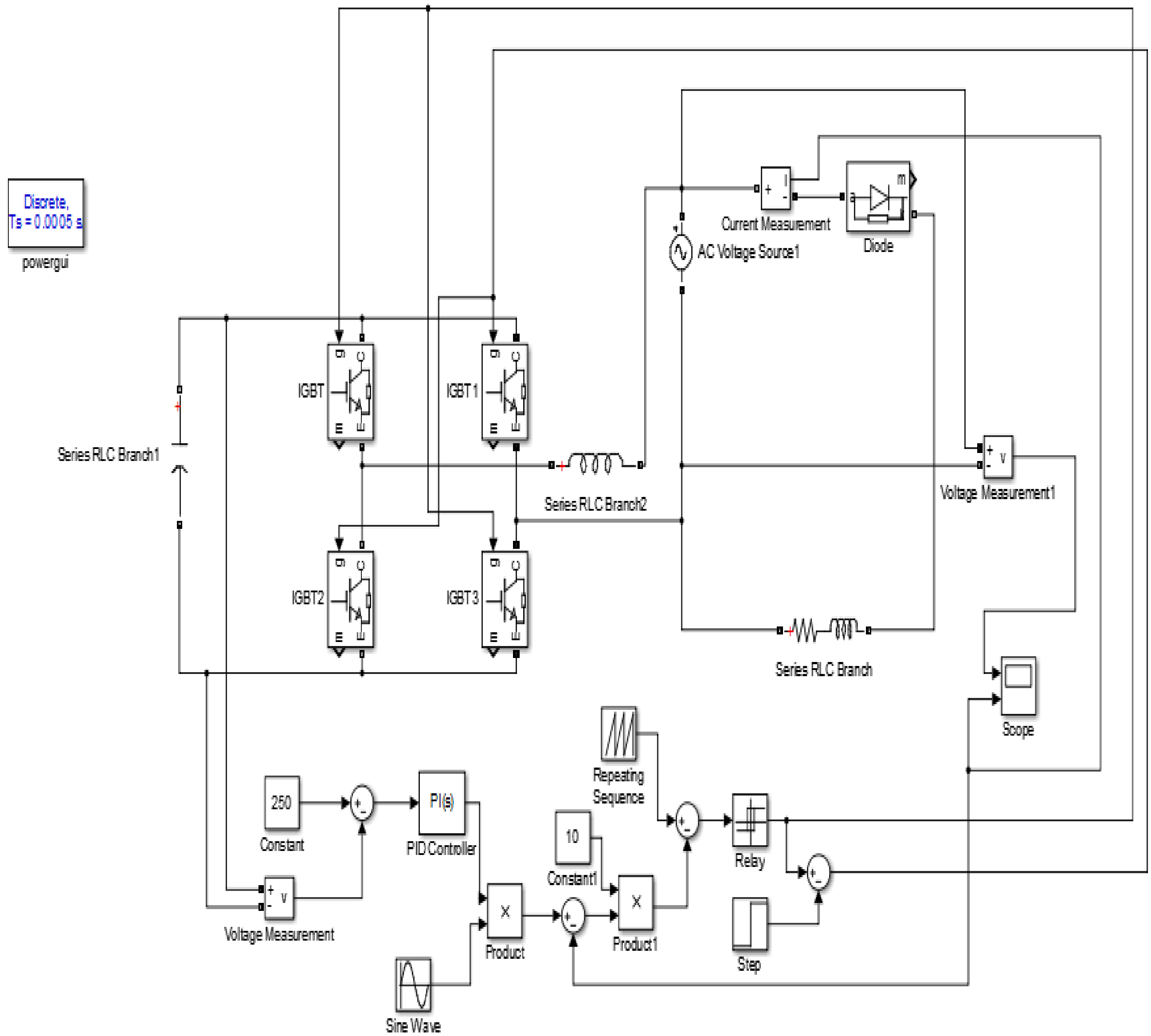

Fig.8 Matlab Simulation for Half Wave Rectifier

CHAPTER 4

SIMULATION RESULTS

4. Simulation Results

The following graphs are the waveforms of the full wave rectifier.

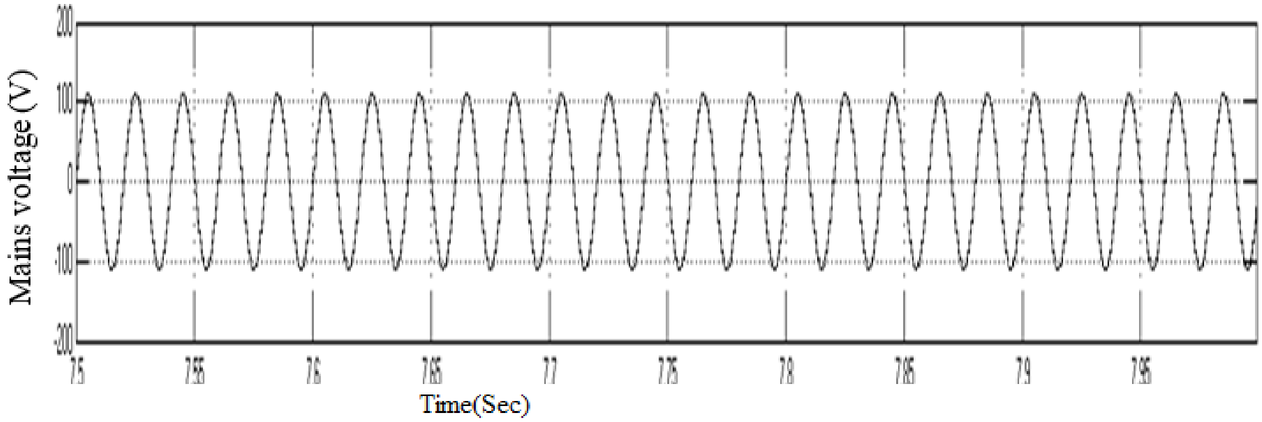

Fig.9 The Mains Voltage Waveform for the Full Wave Rectifier Load

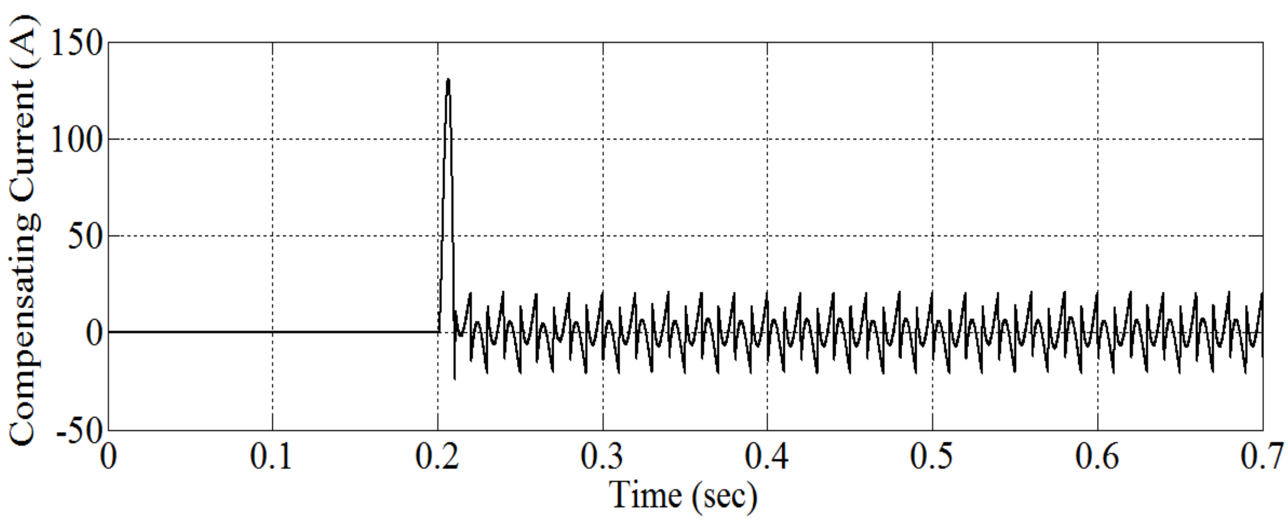

Fig.10 The Compensation Current Waveform for Full Wave Rectifier Load

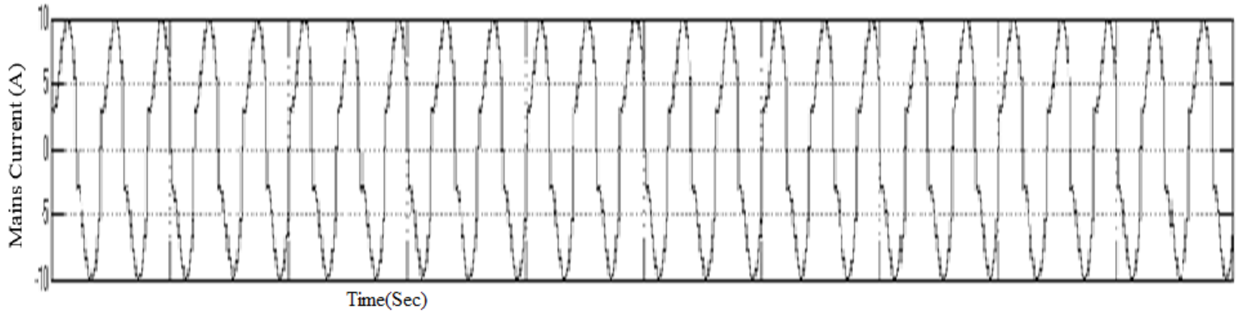

Fig.11 The Mains Current Wave Form for Full Wave Rectifier Load

The following graphs are the waveforms of the half wave rectifier.

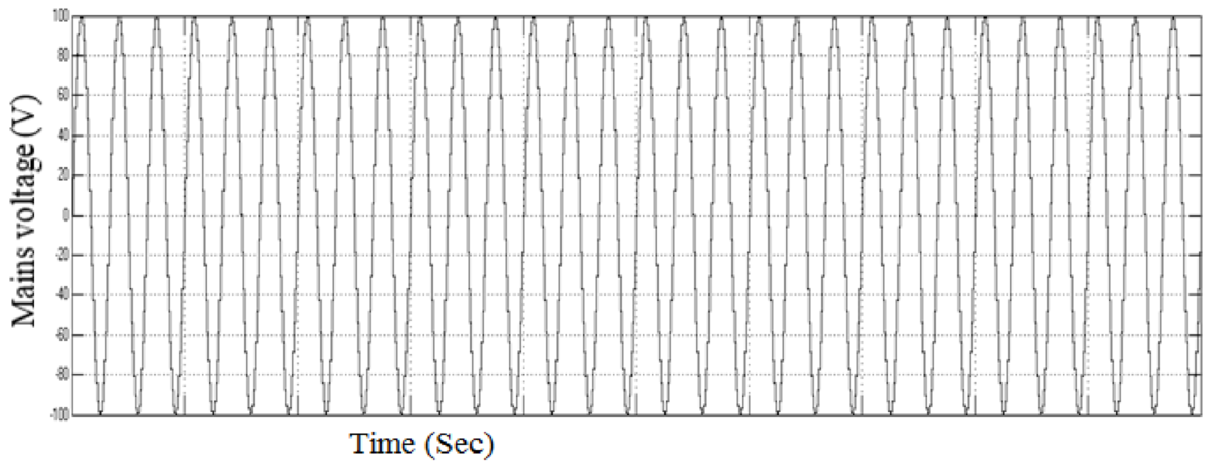

Fig.12 The Mains Voltage Waveform for the Half Wave Rectifier Load

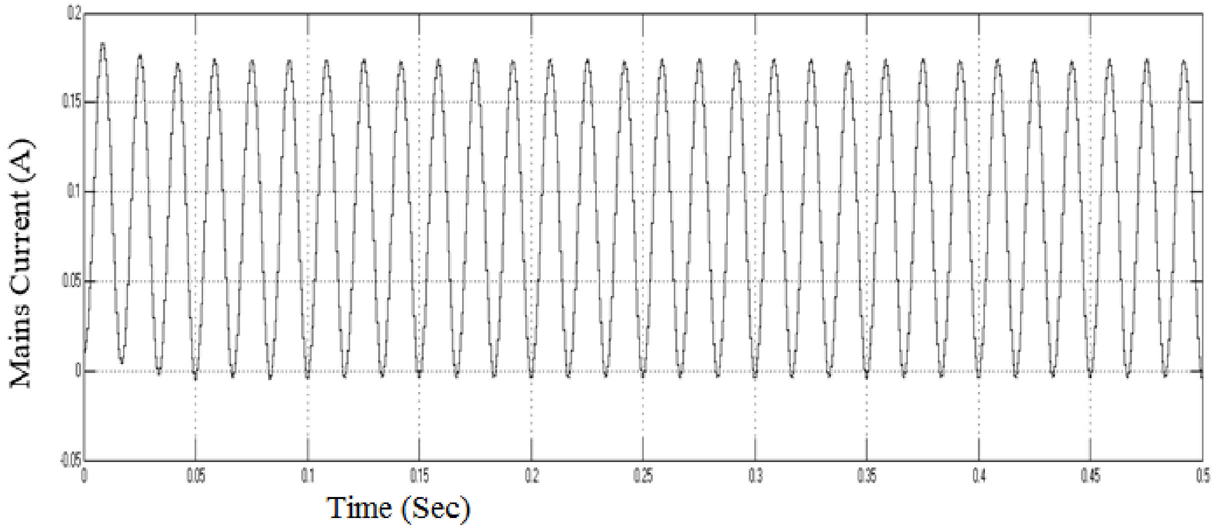

Fig.13 The Mains Current Waveform for Half Wave Rectifier Load

CHAPTER 5

Hardware Implementation

5.1 Component Description for Hardware Design

- 5.1.1 Single phase variac
- 5.1.2 IGBT based inverter
- 5.1.3 Single phase rectifier
- 5.1.4 Current Sensor
- 5.1.5 Voltage Sensor
- 5.1.6 Gate Driver
- 5.1.7 Filter inductor

CHAPTER-5 :

5.1 Component Description for Hardware design:

This chapter descries the various components required to establish the experimental set up. The entire hardware set up used for experimental purposes can be categorized into

1. Single phase Variac
2. IGBT based inverter
3. Single phase rectifier
4. Signal conditioning circuit
5. Filter inductor
6. Source inductor
7. DC link capacitor
8. R-L load

Experimental Setup:

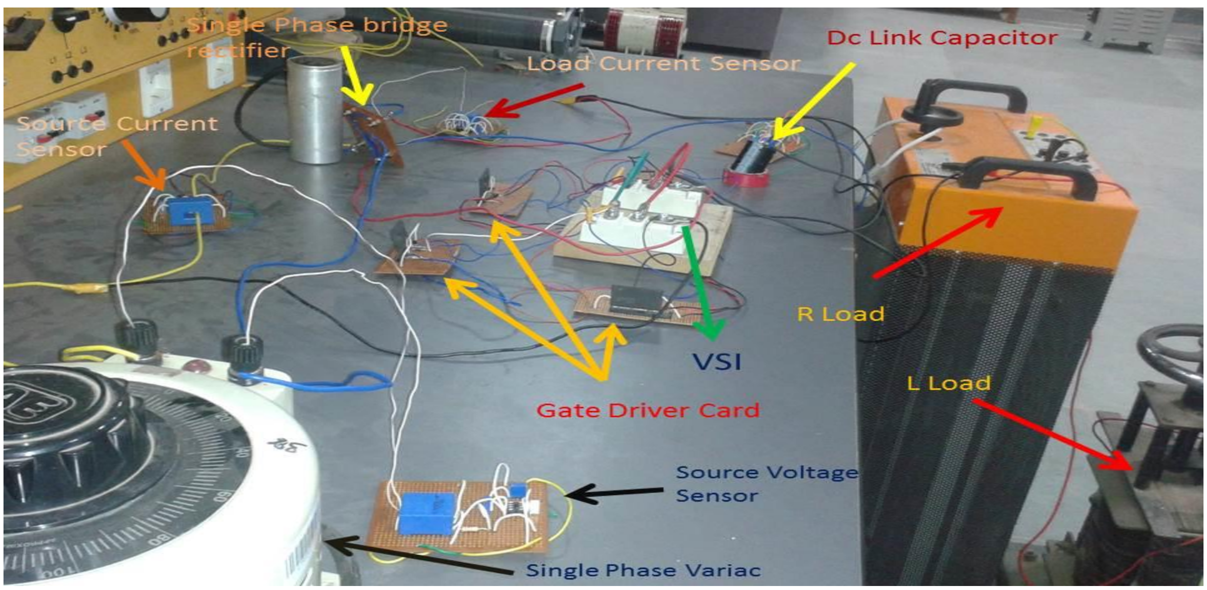

Fig.14 The Experimental Setup

5.1.1 Single Phase Variac

It was used to provide supplied voltage of 230 Volt (r.m.s) required for experimental set up.

5.1.2 IGBT Based Inverter

Single phase voltage source inverter for the experiment is developed by using four IGBT's as the switching devices. The IGBT's purchased are of SEMIKRON, SKM150GB063D made (600 volt, 175 ampere) and will be driven by the gate driver card VLA517-01R.The schematic of the developed VSI is shown in the Fig.15.

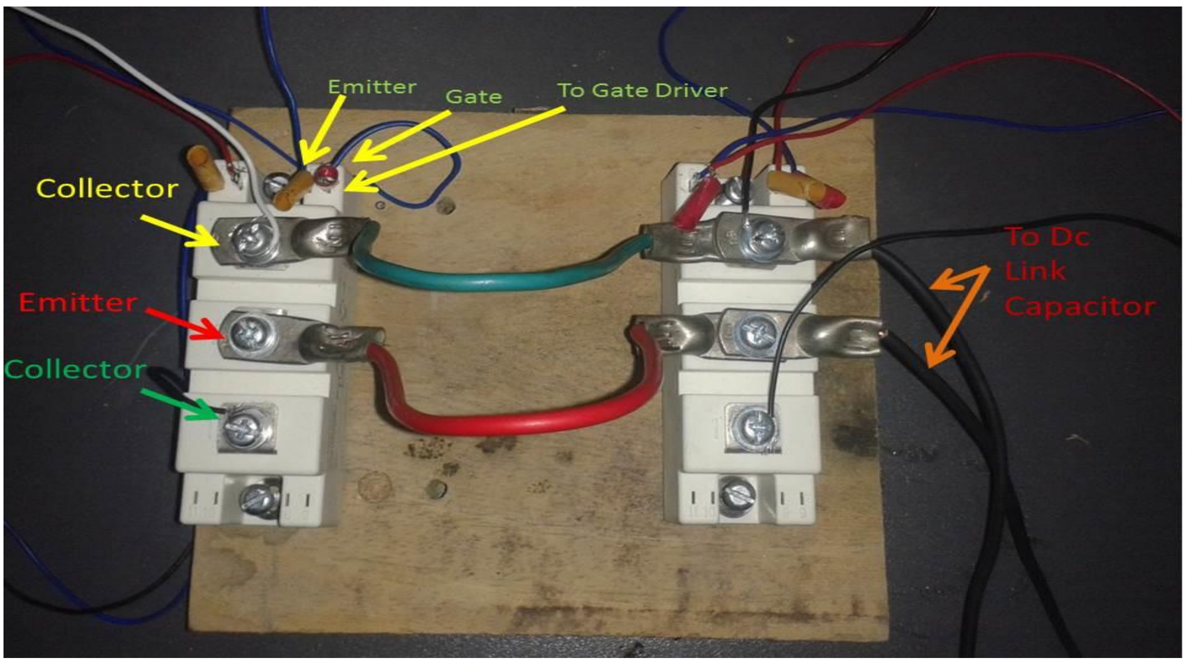

Fig.15 IGBT Switch

5.1.3 Single Phase Rectifier

The combination of single phase rectifier and R-L load will be used for creating harmonics in the source current.

5.1.4 Current Sensor

For the control scheme, source current and load current have to be sensed. Two LEM manufactured current transducers LA 55-P, will be used to sense respective currents.

The schematic of current sensor is shown in Fig.16.

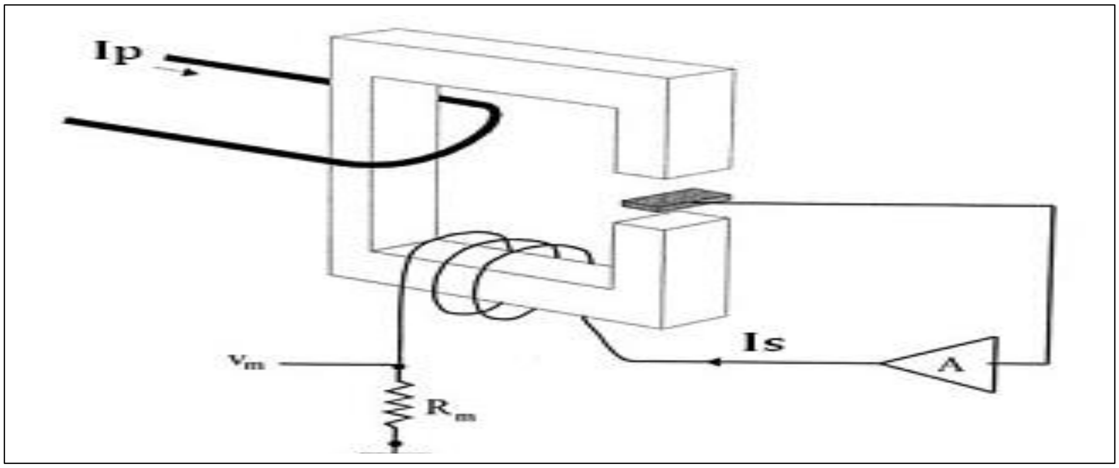

Fig.16 Schematics of the Current Sensor

The magnetic flux created by the primary current is balanced through a secondary coil using Hall device and associated electronic circuit.

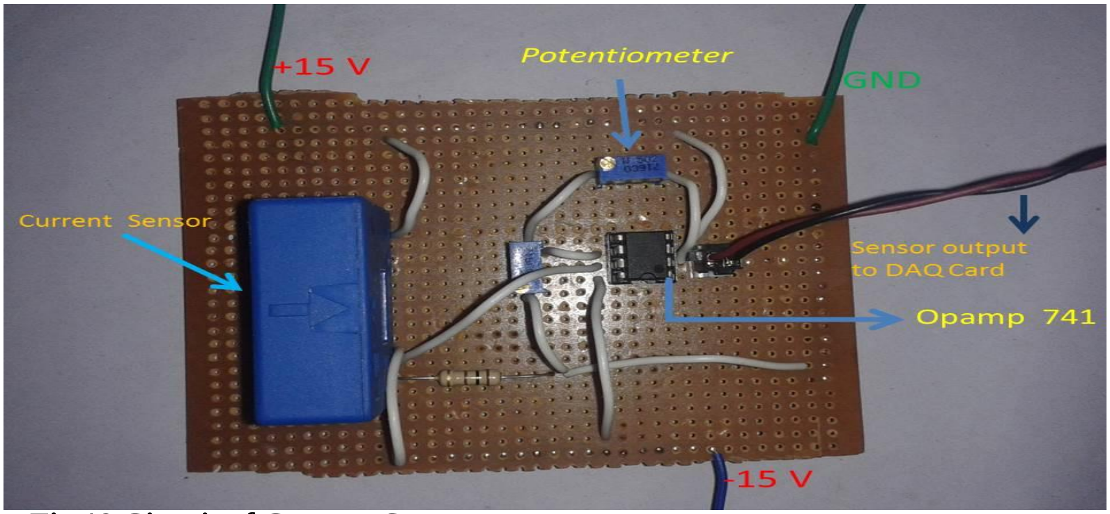

Fig.19 Circuit of Current Sensor

The number of secondary turns (Ns) is 1000 and the maximum value of secondary current (Is) is 50mA. Primary current (Ip) is the current that is to be measured. The magnetic flux created by the primary current is balanced through a secondary coil using a Hall device and associated electronic circuit. The relation given by the following Equation holds true during operation.

$$Np \times Ip = Ns \times Is$$

Where, Np is number of primary turns. In the experiment, Np = 1, thus a primary current up to 50A can be safely measured. Since the turn ratio is constant, the secondary current is an exact representation of the primary current. The output signal is the voltage drop on the resistance Rm caused by the secondary current. A 100Ω resistance is selected as Rm. This output signal needs to be scaled within the analog input limits (-10V to +10V) of data acquisition card, which is done by a non-inverting opamp configuration. Two variable resistances, Ri and Rf, are used to select a proper gain. The current sensor and opamp both require ±15V supply for their operation which is provided by DC power supply module. It is then calibrated to find the exact relation between input current and output voltage.

Two current sensor cards are required for sensing

1. Source current

2. Load current

Current sensor card for measuring source current:

Current sensor card for source current measurement was designed for measuring alternating current of maximum of 15A (r.m.s). The sensor is calibrated such that sensor output is 1V for 2A of input current to be sensed. The curve fitting formula for current sensor card for measuring panel voltage is computed using MATLAB as

$$v_{out} = 2.189 \times i_{source} - 0.1207$$

Current sensor card for measuring load current :

Current sensor card for source load measurement was designed for measuring alternating current of maximum of 40A (r.m.s). The sensor is calibrated such that sensor output is 1V for 2A of input current to be sensed. The curve fitting formula for current sensor card for measuring panel voltage is computed using MATLAB as

$$v_{out} = 2.192 \times i_{load} + 0.1081$$

The curve obtained from curve fitting tool of MATLAB for calibrating the current sensor (source) is shown in the Fig.20

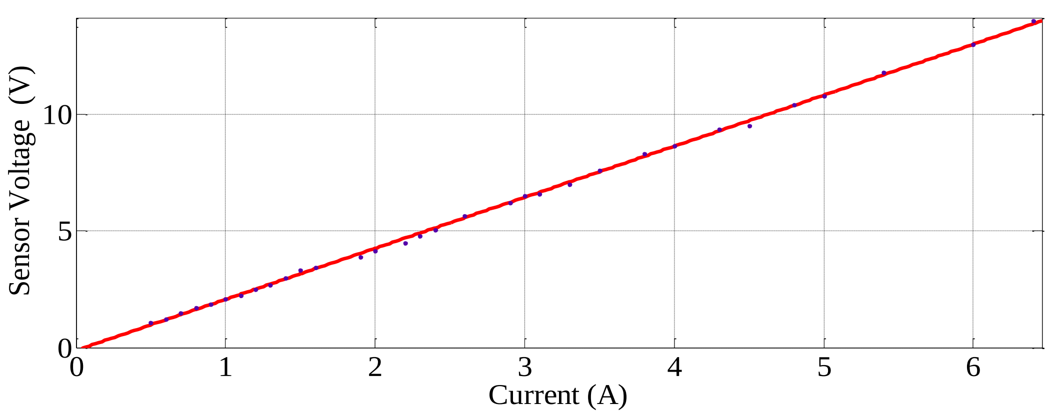

Fig.20 Graph for Calibration of Current Sensor

5.1.5 Voltage Sensor

Source voltage, load voltage dc-link capacitor voltages have to be sensed accurately for proper operation of controller. Three LEM manufactured voltage transducer LV 25-P will be used to sense respective voltages. The complete specification of voltage sensor is provided in Appendix B. The voltage sensor used is Hall Effect based voltage transducer. It can measure up to ±500V. The primary current generated from primary voltage and an external resistor R_{in} creates primary magnetic flux. The magnetic flux is connected to the magnetic circuit. The hall device in the air gapped magnetic core provides a proportionate voltage to magnetic flux. This voltage and associated electronic circuit are used to generate the secondary (compensating) current that is an exact representation of the primary voltage. The secondary current is passed through measuring resistance R_M. The voltage drop across R_M is provided to op-amp LM741, operated in non-inverting mode to scale the sensor output signal to a range suitable for ADC pins i.e. -10 to 10.V. The voltage sensor and op-amp both require ±15V DC supply.

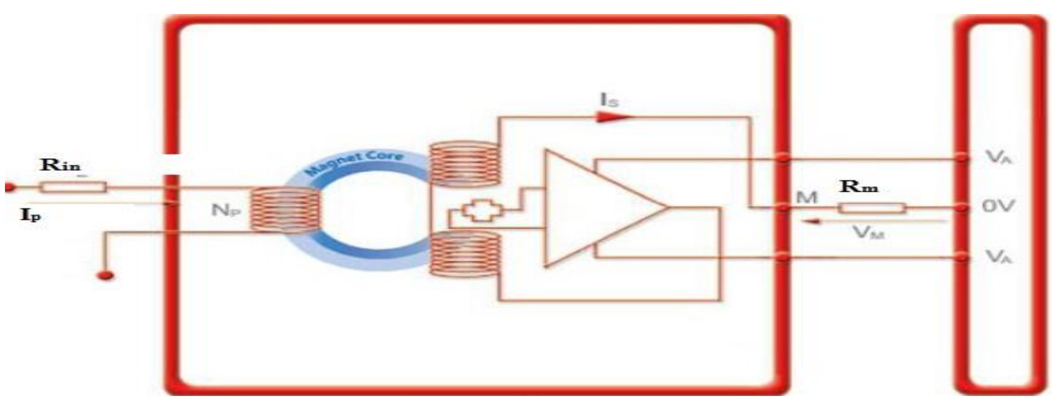

Fig.21 Schematics of the Voltage Sensor

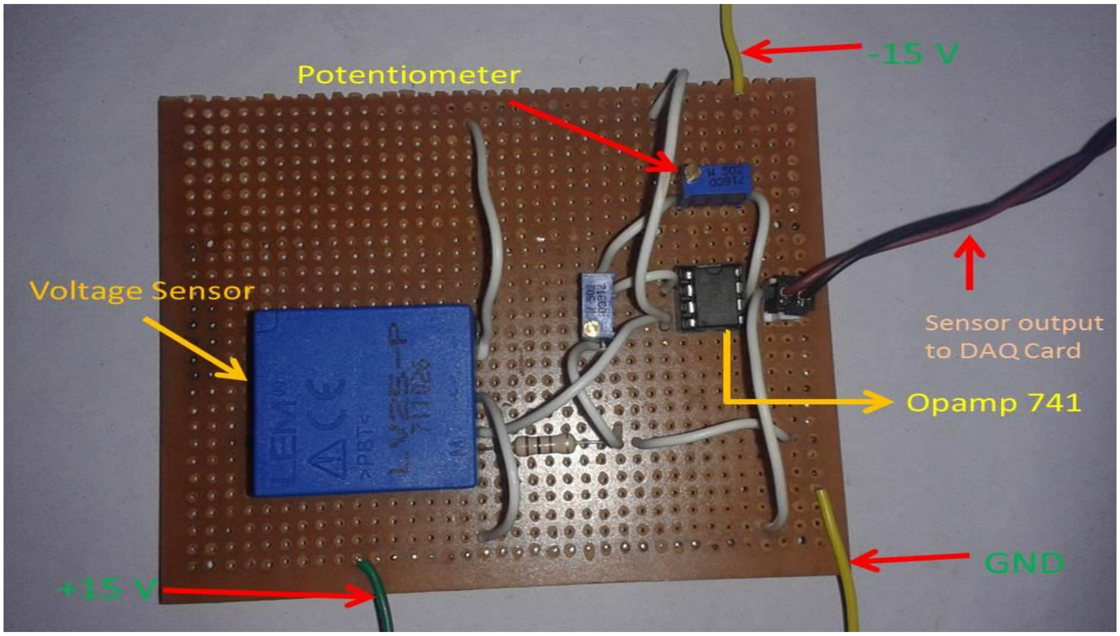

Fig.22 Hardware Circuit for Voltage Sensor

The curve fitting formulas for three voltage sensors are computed as

For source voltage sensor, $v_{out} = 0.0923 \times v_{source} + 0.2380$

For load voltage sensor, $v_{out} = 0.0904 \times v_{load} + 0.2541$

For DC link voltage sensor, $v_{out} = 0.0941 \times v_{DC\_link} + 0.3541$

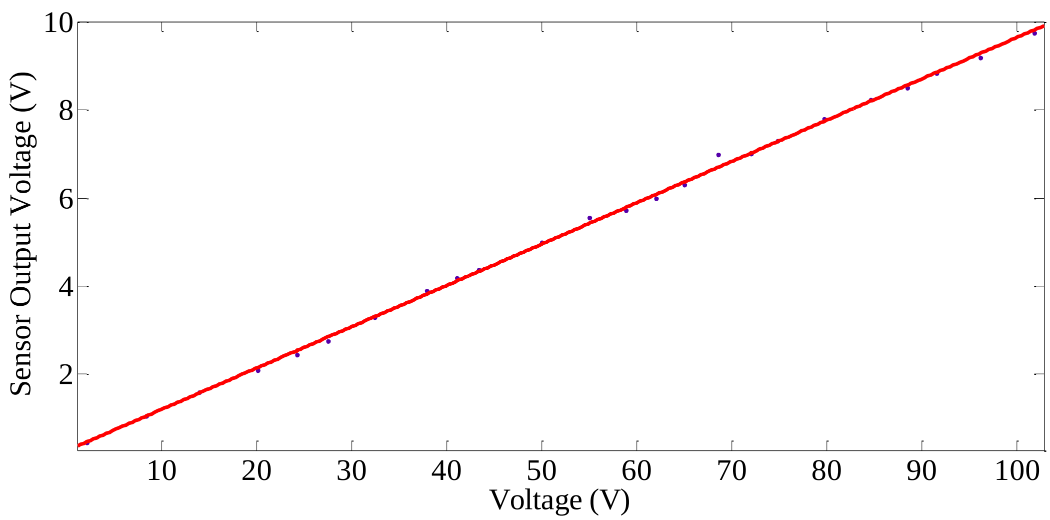

Fig.23 Graph for Calibration for Voltage Sensor

5.1.6 Gate Driver

High performance FUJI's hybrid IGBT driver IC, VLA517-01R will be used to provide the necessary driving signals to the IGBT across the gate emitter terminals. This hybrid IC is a circuit designed for driving n-channel IGBT modules. An optocoupler is used in this chip to provide the required isolation between the signal side of the chip and the power side. The input to the chip is a digital signal of +5V as logic high and 0V as logic low and the corresponding outputs are +15V and -5V. Output of this chip is connected through a proper gate series resistance (R_g=25Ω) across the gate emitter terminals of the corresponding IGBT, which is to be driven. The input logic signal given to the chip should be capable of driving a current of 10mA for the satisfactory operation of this chip. The circuit diagram implemented in the present work for the IGBT driver is shown in Fig.22.

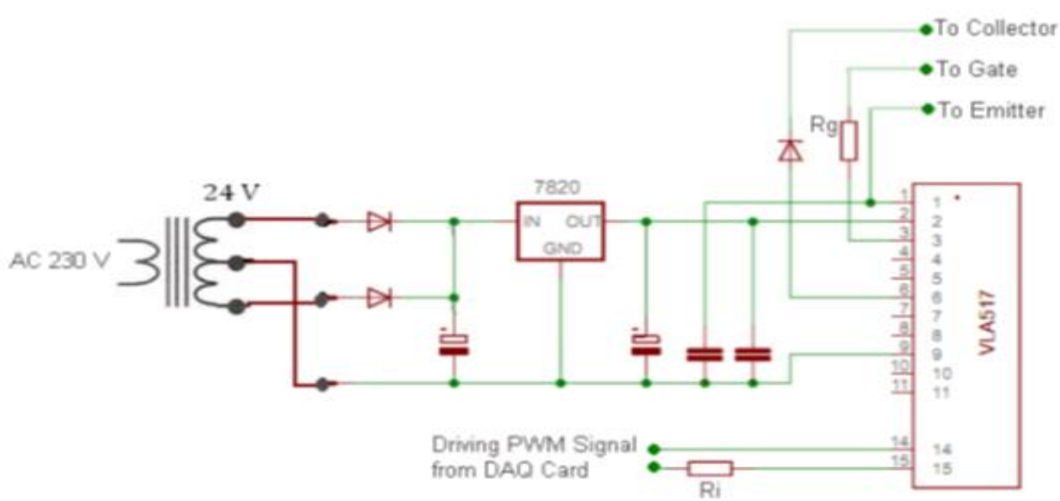

Fig.22 Schematics of the Gate Driver Circuit

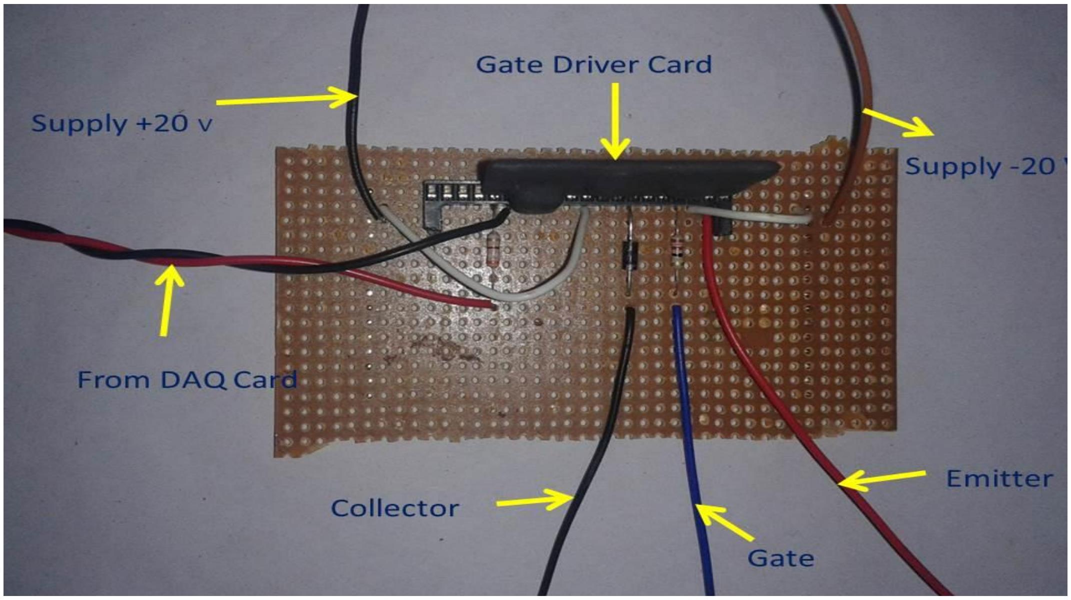

Fig.23 Hardware Circuit for Gate Driver

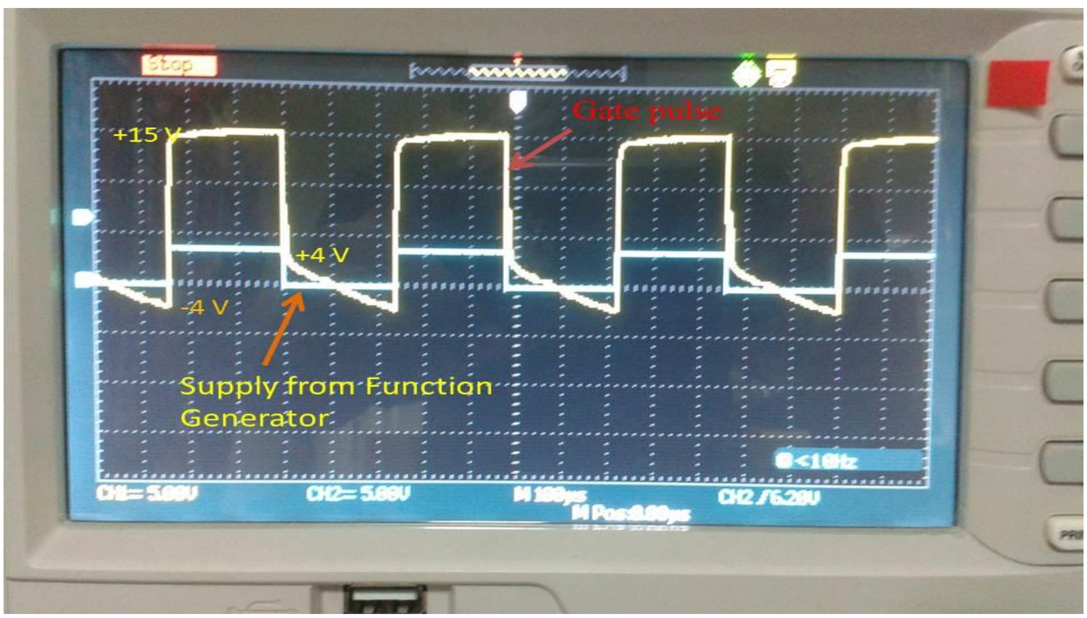

Fig.24 The Output of Gate Driver on CRO

5.1.7 Filter Inductor

The purpose of using filter inductor is to eliminate very high frequency component from filter injected current.

CHAPTER 6

CONCLUSIONS

6. Conclusions

By using appropriate value of K_i and K_p with error amplifier and PWM modulator the reactive power can be provided through capacitor. Hence minimizing the harmonics and improving the power factor. And using passive high pass filter in parallel with proper R_h , L_h and capacitance (C_h)value harmonics can be minimized. This simulation is to be verified through the experimental setup but due to failure of the setup, results shown are of simulation outputs. From the simulation results it is concluded that it is very important to remove harmonics and active power filter makes it possible in well-mannered way. This also provides the reactive power compensation.

Future Scope for Further Research

With the use of DAQ card and the DC supply the setup will be completed and then the simulation results can be verified. With this the research can be concluded that active power filter is very good method for compensation of harmonics and also a very well and improvised method for the reactive power compensation.

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